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USING THE SHIPCASE PROJECTION SYSTEM TO SIMULATE CASUALTY AND ILLNESS RATES AMONG FORCES AFLOAT

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SUMMARY

Problem

Modeling of medical resource requirements during naval operations requires accurate projections of wounded-in-action (WIA), killed-in-action (KIA), and disease and non-battle injury (DNBI) rates.

Objective

A shipboard casualty projection system (SHIPCAS) has been developed. This paper provides the statistical foundation of SHIPCAS and is a guide for SHIPCAS users.

Approach

Casualty data were extracted from eighty U. S. naval operations during World War II. The statistical distributions of hit rates, WIA, KIA, and DNBI incidence were partitioned into five battle intensities and analyzed by weapon systems and ship types. This data provides the basis for ship hit and casualty incidence projections.

Results

The SHIPCAS shipboard casualty projection system simulates casualty and illness rates under user defined naval scenarios. Output of the simulated data reflect the salient characteristics of the empirical data.

Conclusions

Knowledge of the distributions of the DNBI and casualty incidence allows the planning of needed medical resources for various naval combat operations.

Using the SHIPCAS Projection System to Simulate

Casualty and Illness Rates Among Forces Afloat

Accurate forecasts of the injury and illness incidence likely to be sustained during naval combat operations allow sufficient medical resources to be programmed to treat expected patient flow while minimizing over allocation of resources. A planning tool called the shipboard casualty projection system (SHIPCAS) has recently been developed to forecast shipboard casualty incidence. The present report details use of SHIPCAS and the statistical underpinnings upon which the projections are based.

SHIPCAS is a forecasting tool that projects WIA (wounded-in-action), KIA (killed-in-action), and DNBI (disease and non-battle injuries) incidence among naval surface forces. By simulating naval combat, SHIPCAS provides medical planners with the injury and illness estimates required to assist in determining the needed medical resources. The SHIPCAS system models casualties afloat by allowing the planner to define a specific scenario in terms of task force composition, expected battle intensity, and length of the operation. The model then produces graphical and tabular information detailing the total number of casualties across the operation, the daily average number of casualties, the maximum daily number of casualties, and the casualty rates per 1000 strength per day. In addition to projecting numbers of ships hit and resulting casualties, SHIPCAS also provides estimates of the temporal points in the operation during which shipboard strikes are most likely.

The SHIPCAS model projects casualties separately for combat ships and auxiliary vessels. Combatant ship casualty projections are computed for Destroyers, Carriers, Frigates, and Cruisers and auxiliary ship casualties are projected for Cargo, Transport, Minesweepers, Torpedo Boats, and Tank Landing Craft. Further, casualty estimates are provided for two levels of care: presentations and admissions. Presentations represent all injuries and illnesses that require treatment that precludes returning the individual to duty immediately and admissions are the subset of presentations that are retained for treatment of three days or longer.

Two major components are essential to shipboard casualty projections: 1) calculations of the rate of hits that ships would be subject to under various combat situations, and 2) the casualties which would result from a strike on a surface vessel. In order to provide operationally-relevant projections, historical data were extracted and analyzed in terms of hit rates and resulting casualties. Studies conducted at the Naval Health Research Center[1,2] examined the frequencies and rates of casualties sustained during various World War II naval operations. Data from these investigations provided a basis to segregate the operations into definable battle intensities, within which statistical parameters could be individually analyzed. Five separate battle intensities were assigned (no combat, light, moderate, heavy, intense) and ship attack rates, WIA and KIA frequencies, and distributions of weapons and ship types were then examined for each battle intensity. Shipboard DNBI rate projections are based solely upon ship type because, while DNBI rates were found to vary by size of ship[3], combat status had but a slight impact on illness

incidence[4,5].

The present report describes the SHIPCAS shipboard casualty projection system in two sections. Part I is a user's guide that documents the steps necessary to run the shipboard casualties simulation. Part II then addresses the statistical underpinnings upon which the casualty projections are based.

PART 1 -- USE OF THE SHIPCAS CASUALTY PROJECTION SYSTEM

SHIPCAS System minimum requirements

- an IBM or IBM-compatible PC
- an EGA, VGA, or SVGA monitor
- 640k memory
- a hard drive with 2MB free disk space
- DOS version 4.01 or higher
- Microsoft Windows 3.1 or higher
- serial mouse

Setup

SHIPCAS must be installed on a hard disk for execution. To install the SHIPCAS system:

1. Put disk in 3½" floppy drive (usually A or B).
2. At DOS prompt, type "a:\install" (or "b:\install"), then press *ENTER*.

This begins the installation process that places the SHIPCAS casualty projection system onto the hard drive. The program will be installed in its own directory called c:\shipcas, and will include all files necessary for implementation. Further, the installation process will add a number of dynamic link libraries to the windows directory.

Once installed, SHIPCAS can be run either by typing "shipcas" at the DOS prompt (which will start Windows and run the program), or by choosing File|Run from the Program Manager and typing "shipcas" at the prompt.

Main Menu

The main menu contains all the commands that run SHIPCAS. The first item, EXIT, allows the user to leave the program. Selection of the second item, the EDIT option, allows the user to define the TASK FORCE and SCENARIO. The RUN option executes the SHIPCAS simulation for either a SINGLE iteration or across MULTIPLE iterations of the same scenario. After the RUN option has been executed, the VIEW menu becomes active so the user can display the following options: HIT DISTRIBUTION, CASUALTY DISTRIBUTION, DNBI DISTRIBUTION, and SUMMARY statistics generated by the model.

Designing a Scenario

Simulation of the casualties sustained afloat using SHIPCAS begins with defining a task force and battle intensity of the operation. To choose the ship types involved in the scenario, TASKFORCE is selected under the EDIT option. From this sub-menu, selection of MAJOR COMBATANTS brings up a dialog for selection of the warships to be included in the task force. The options provided include Destroyers, Carriers, Frigates, and Cruisers as seen in Figure 1.

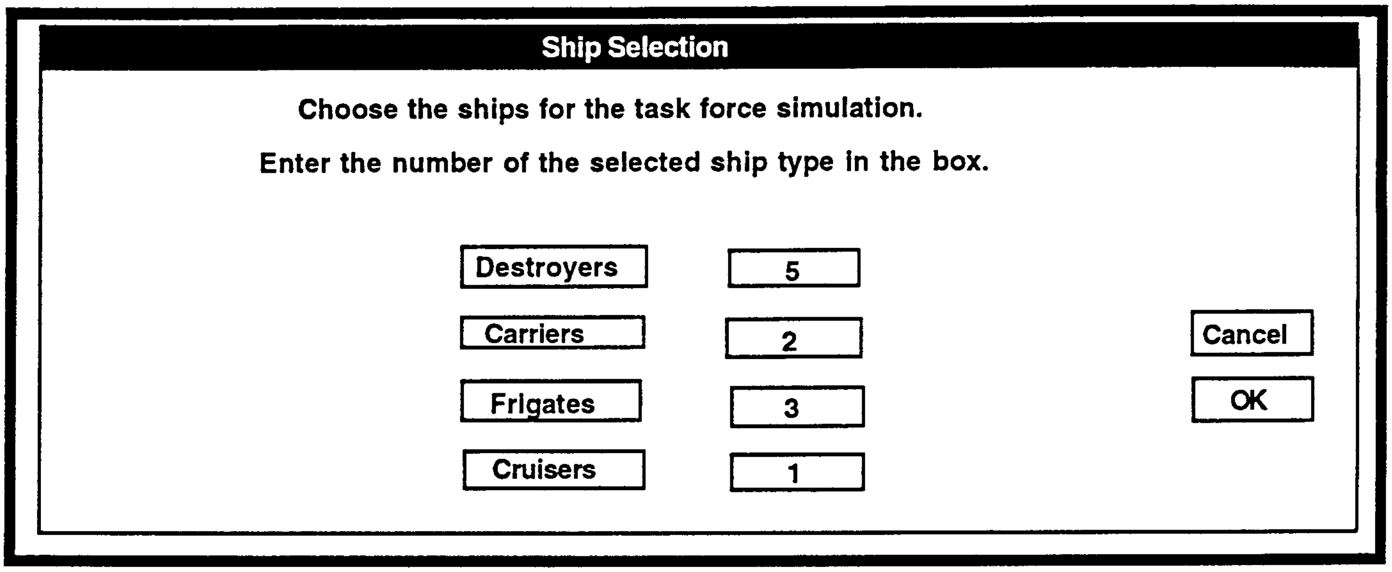

Figure 1. Major combatant ship selection screen.

To input the desired number of each ship type, the user first selects the ship type box by either clicking on that box or by use of the *TAB* key to toggle down to the correct selection, and then type the number ships of that ship type to be assigned to the hypothetical task force. If an error is made during input, the user may return to that selection box and type in the correct information, or click on the *CANCEL* button to start over with all selections back at their original values. When the number of each ship type has been specified, the user either clicks the mouse on the *OK* button, or presses the *RETURN* key.

In addition to the major combatants, the task force may also include auxiliary ships. Consequently, the user may specify auxiliary ships for the scenario by selecting EDIT|TASKFORCE|AUXILIARIES. The number of auxiliary ships are specified in the same manner as for the major combatants. Options for types of auxiliary ship are Cargo, Transport, Minesweeper, Tank Landing Craft, and Motor Torpedo Boat, as seen in Figure 2.

Once the composition and size of the auxiliary ship component of the task force have been set, clicking on the OK button will return the user to the main menu. Then the operational scenario may be defined by selecting SCENARIO under the EDIT option. The resulting screen permits the user to assign a battle intensity level and to designate the length of the operation. The choices for battle intensity are None, Light, Moderate, Heavy, and Intense. (Figure 3).

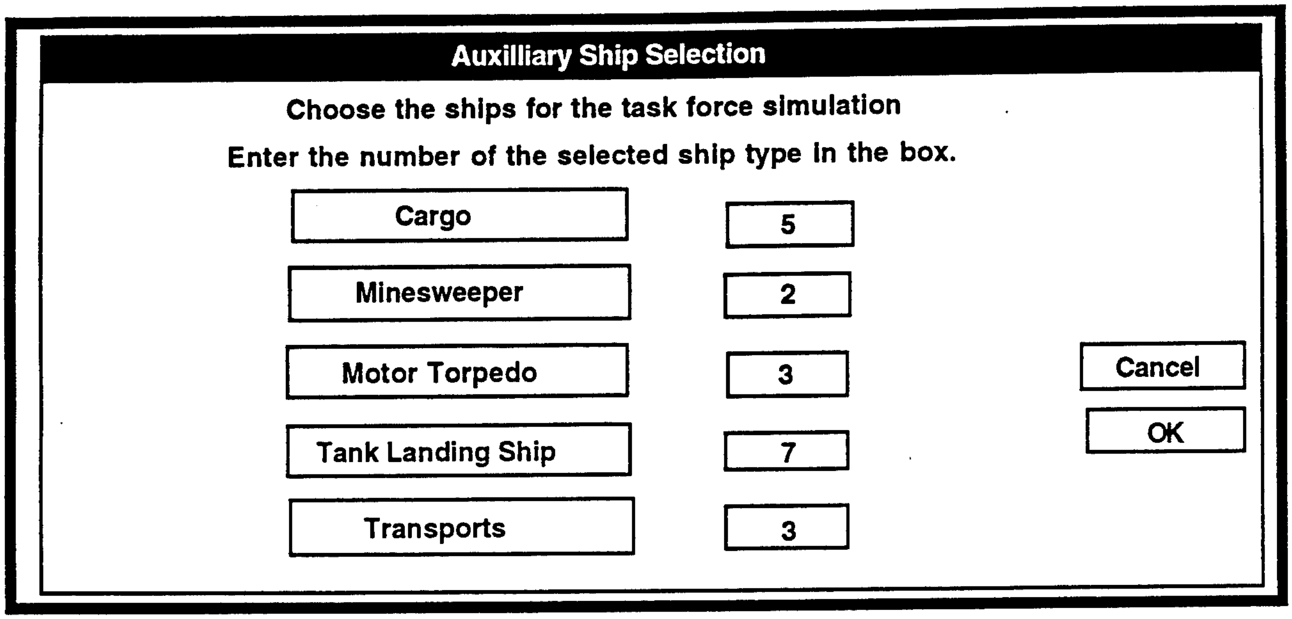

Figure 2. Auxilliary ship selection screen.

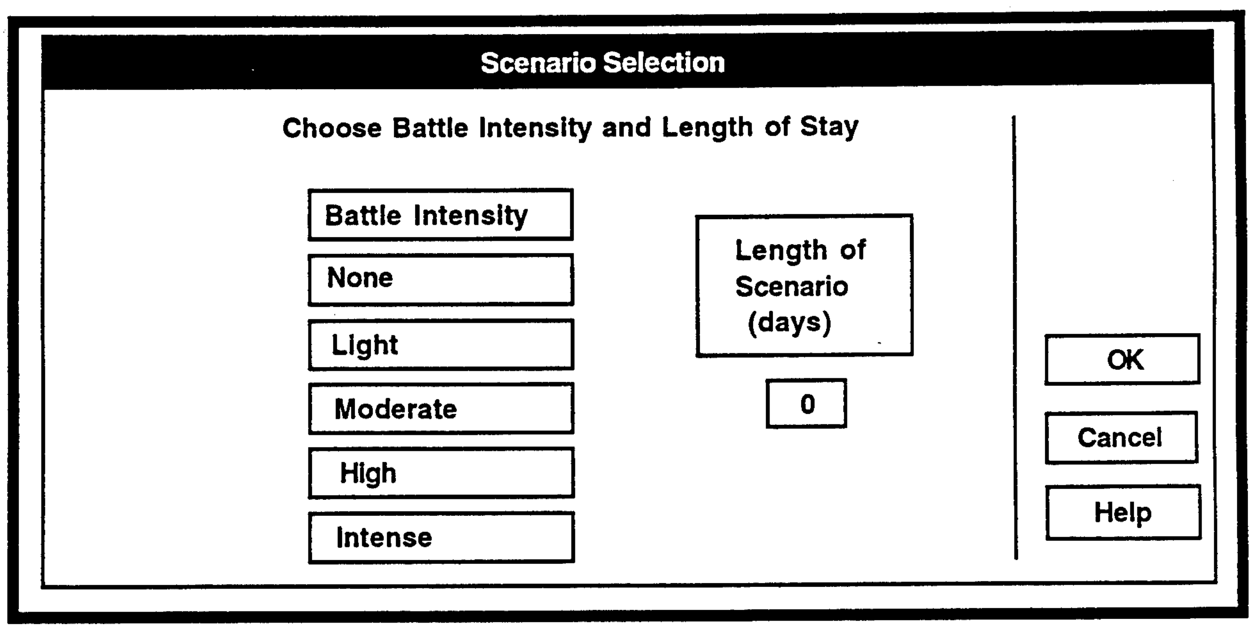

Figure 3. Scenario selection screen.

The battle intensity levels reflect ship hit rates computed from the empirical data corresponding to various combat operations[1]. Ship hit rates are a function of 1) the number of U.S. ships that were hit by weapons, 2) the number of U.S. ships involved in the operation, and 3) the lengths of time each ship participated in the operation. The battle intensity levels are represented by the partitioning of the range of hit rates into five combat intensities as explained in the second part of this report.

Finally, the user enters the length of the operation on this screen in terms of the number of days the operation will last. Once the battle intensity and length of operation parameters are defined, clicking on the *OK* button will return the user to the main menu.

<u>**Running the Model**</u>

After the required user input has been entered into the model, the simulation may be executed under the RUN option in one of two modes: SINGLE scenario run mode yields casualty data based on a single iteration; MULTIPLE scenario run mode computes casualty statistics across a user-specified number of simulated operations. The SINGLE iteration mode yields a graph projecting temporal points in the operation in which the ship hits occur, a graph projecting casualties on a daily basis, casualty information by ship type, and summary statistics across the operation. Selection of the MULTIPLE option requires the user to then designate the number of iterations of the simulated scenario across which the casualty statistics should be calculated. The projection program then computes means across the iterations for the number of ship hits, frequencies and rates of WIA, frequencies and rates of KIA, maximum daily casualty load, and total operational casualty load. Each of these computations is based on distributions[6] generated with the aid of random number generators. A tabular display of projected DNBI frequencies and rates, for each ship type in the task force, is available in both SINGLE and MULTIPLE iteration mode.

<u>**Viewing the Results**</u>

The VIEW option from the main menu allows the user to choose from HIT DISTRIBUTION, CASUALTY DISTRIBUTION, DNBI DISTRIBUTION, AND SUMMARY statistics sub-options to view the output of the model. The HIT DISTRIBUTION is available separately for major combatant ships (seen in Figure 4) and auxiliaries vessels, and is a typical display of the number of hits that occur for each 'ship type by weapon type combination' as well as overall totals.

Additional information in the form a graphical display of the number of hits that occurred each day of the operation can be obtained by clicking on the GRAPH button. Figure 5 is a an example of this function. Removal of the graph from the screen is accomplished by clicking twice on the box in the top left corner of the graph window or by clicking the *OK* button.

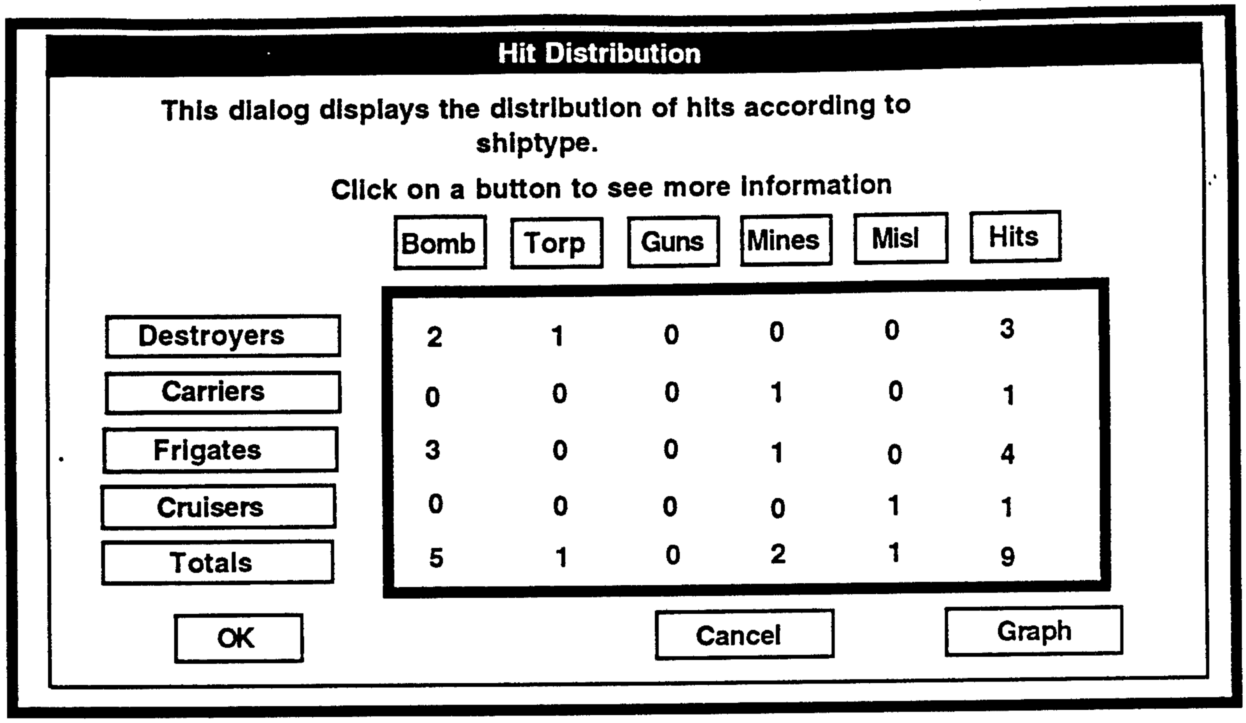

Figure 4. Hit distribution screen for major combatants.

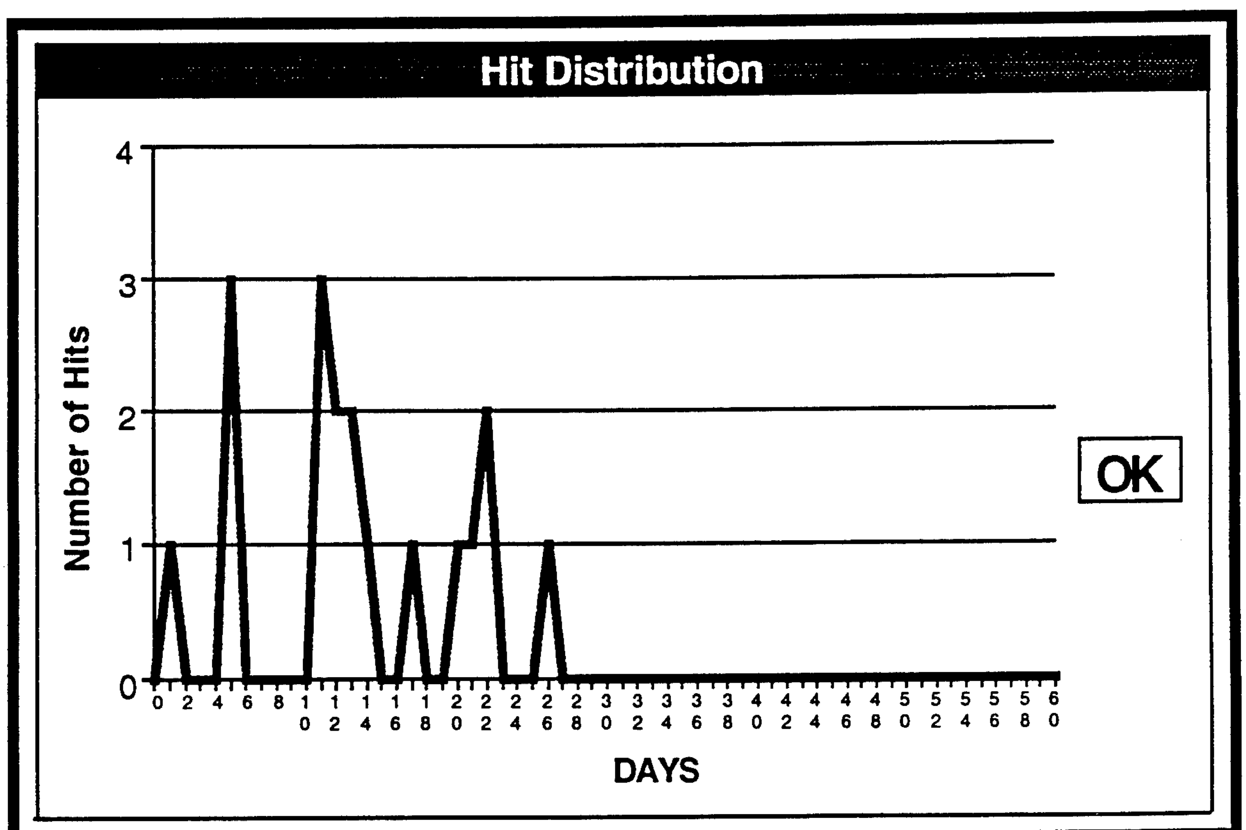

Figure 5. Graphical display of the temporal distribution of hits.

The second choice of viewing options is the CASUALTY DISTRIBUTION screen. This window depicts WIA and KIA frequencies and rates per 1000 strength per day, for both combat and auxiliary ships. (Sample output for Combatant Ships is shown in Figure 6). A graphical display of the projected casualties on a daily basis is available by clicking on the GRAPH button. Figure 7 displays a typical graph of casualties over time available through this option.

Casualty Distribution

This dialog displays the distribution of casualties according to shiptype.

	Presentations		Admissions			
	WIA	WIA Rate	WIA	WIA Rate	KIA	KIA Rate
Destroyers	125	2.97	87	2.08	247	5.86
Carriers	144	0.32	100	0.23	115	0.26
Frigates	19	0.85	13	0.60	14	0.63
Cruisers	18	0.10	12	0.07	22	0.12
Background	24	0.03	16	0.02	0	0.00
Totals	330	0.48	230	0.33	398	0.58

OK Cancel Graph

Figure 6. Casualty distribution screen; major combatants

The DNBI DISTRIBUTION screen (sample output shown in Figure 8) is similar to the CASUALTY DISTRIBUTION screen except that it provides tabular information on the disease and non-battle injuries projected to occur during the operation. The last option within the VIEW menu is the SUMMARY screen. This option provides a tabular display of summary statistics across the operation. These statistics include mean daily casualty frequencies and mean casualty rates per 1000 strength per day as well as the maximum single day casualty load and total operation casualty load. An example of this screen is shown in Figure 9.

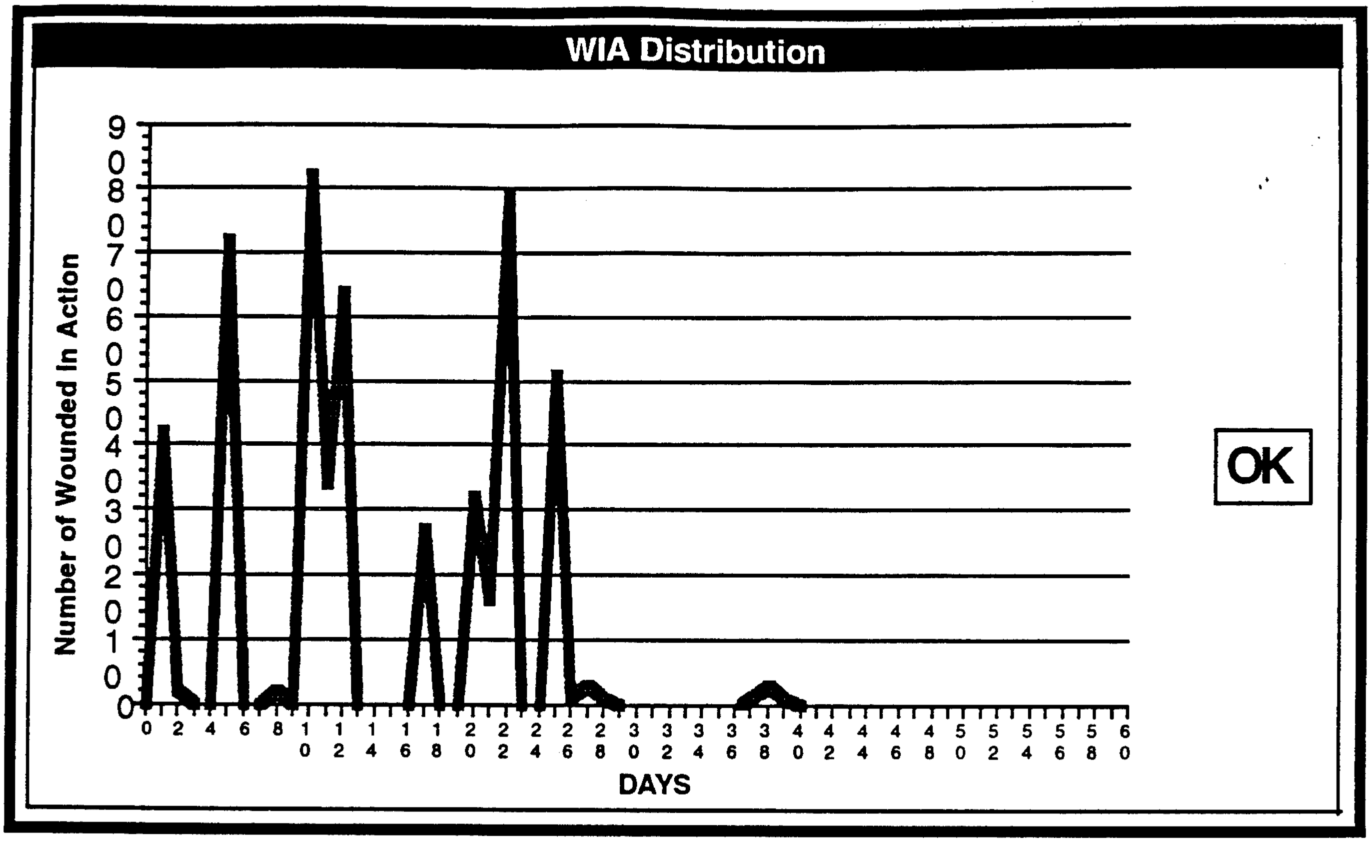

Figure 7. Graphical display of the temporal distribution of WIA.

Disease and Non-Battle Injuries

	DIS	DRATE	NBI	NRATE
Destroyers	26	0.31	4	0.05
Carriers	186	0.21	31	0.03
Frigates	14	0.31	2	0.05
Cruisers	99	0.27	16	0.04
Totals	326	0.24	54	0.04
Cargo	20	0.33	3	0.05
Minesweepers	10	0.43	2	0.06
Motor Torpedo Boats	2	0.42	0	0.05
Tank Landing Ships	9	0.34	1	0.05
Transports	32	0.36	5	0.06
Totals	73	0.36	12	0.06

OK

Cancel

Figure 8. DNBI distribution screen.

Casualty Summary

Major Combatants		WIA Pres	WIA Adm	KIA	Hits per 100 ship days
MEAN	Rate per 1000 strength	0.05	0.04	0.05	0.00
	DAILY FREQUENCY	1.49	1.04	1.27	0.12
MAX	DAILY FREQUENCY	68	47	56	3
AUXILLIARY					
MEAN	Rate per 1000 strength	0.56	0.39	0.35	0.06
	DAILY FREQUENCY	2.30	1.61	1.41	0.26
MAX	DAILY FREQUENCY	91	63	63	5

OK

CANCEL

TOTALS	MEAN WIA Pres	MEAN WIA Adm	MEAN WIA Pres Rate	MEAN WIA Adm Rate	MEAN KIA Rate
Across all ships (daily)	3.79	2.65	0.12	0.08	0.08

Total WIA presentations across operation:	199
Total WIA admissions across operation:	139
Total KIA across operation:	151

Figure 9. Summary screen for casualties and hits.

PART II -- STATISTICAL BASIS FOR THE SHIPCAS MODEL

Hit Rates and Battle Intensity

Within SHIPCAS, combat intensity is defined by a range of ship hit rates. Ship hit rates were computed for each of eighty WWII operations analyzed. Because large numbers of ships were involved in many operations and relatively few ships were actually struck, rates were computed as hits per one hundred ship days ((Hits/Ships*Days)*100). The data across all operations yielded a range of 0.0 to 50.00 hits per 100 ship days. These rates were partitioned into five groups of near equal observations to represent varying battle intensities. The range and mean for each battle intensity level are:

	RANGE	MEAN
NONE	0.0000	0.0000
LIGHT	0.0295 to 0.2579	0.1739
MODERATE	0.2738 to 0.6095	0.4297
HIGH	0.7067 to 3.8462	1.0236
INTENSE	5.8824 to 50.000	11.7798

Examples of WWII operations within each intensity level include NONE: Western Caroline Islands Operation; LIGHT: Marshall Islands Operations; MODERATE: Gilbert Islands

Operation; HEAVY: Midway; INTENSE: Guadalcanal. The first step that the SHIPCAS program performs is the simulation of the number of hits that occur for the user-designed scenario. Variates from a normal distribution are generated around the estimated parameters of the hit rate for the chosen battle intensity which represent the number of hits occurring during the operation. Statistically, this process is represented by the following:

$$H = (Y/100)S$$

where

H = the number of hits (in the hypothetical operation),
$Y \sim N(\mu,\sigma^2)$, variates from a normal distribution,
μ = mean number of hits per 100 ship days (from the empirical data),
σ^2 = standard deviation of the number of hits per 100 ship days (from the empirical data),
S = the number of days in the operation.

Timing of Hits

The next process is simulation of the temporal points in the operation when each of the hits occurred. Analysis of the empirical data allowed the computation of a mean inter-arrival time between hits (3.8 days). Random deviates based on this mean and drawn from an exponential distribution then provide projected days in the operation on which each hit occurs.

$$T \sim \text{expo}(\beta),$$

T = inter-arrival time,
β = estimated mean of the exponential distribution.

Ship Hit Determination

Examination of the distribution of the ship types that were attacked during the historical scenarios, as well as their overall presence, provides the foundation for the ship hit determinations within the SHIPCAS model. For combatant ships, each ship type category is represented by empirical data for the following ship types: Destroyers: DD; Carriers: CV, CVL, CVE; Cruisers: CA, CL; Frigates: DE. For auxiliary ships, each category is represented by empirical data for the following ship types: Cargo: AK, AKA, AKN; Transports: AP, APA, APD, APH; Minesweepers: AM, YMS, DMS; Tank Landing Craft: LST; Motor Torpedo Boats: PT. The relative risks of each ship type were computed to control percentage of hits for the amount of days of exposure. The distributions of hit percentages, overall presence, and relative risk were:

Combatant Ships	% of hit ships	Ship days %	Relative Risk
Destroyers	55.4	57.3	0.97
Carriers	15.7	12.3	1.28
Frigates	8.2	20.4	0.40
Cruisers	20.6	9.9	2.08

Auxiliaries	% of hit ships	Ship days %	Relative Risk
Cargo	7.1	6.2	1.14
Mine Sweepers	32.0	15.9	2.01
Motor Torpedo Boats	30.6	24.5	1.25
Tank Landing Ships	27.2	43.0	0.63
Transports	3.1	10.4	0.30

To account for the relative risk of ships in the user defined scenario, each empirically computed risk was weighted by the number of ships the user chose of that type:

$$r_k = n_k x_k$$

where:

k = each individual ship category (i.e., destroyers, carriers, etc.),
r_k= the weighted relative risk for ship type k in the user defined task force,
n_k= the number of ships of category k in the task force,
x_k = the relative risk of a ship of category k.

The probability of any individual ship in the task force being hit is then calculated by dividing the relative risk of a ship of that type by the aggregated weighted risks of all ship types: where:

$$Y_i = x_i / \sum_k r_k$$

i = the category of the target ship (i.e., destroyer, carrier, etc.),
Y_i = the probability of an individual ship of type i being hit,
x_i = the relative risk of a ship of category i,
k = each individual ship category (i.e., destroyers, carriers, etc.),
r_k = the weighted relative risk for ship type k in the user defined task force.

With the individual ship probabilities normalized to 100 percent, they are then aggregated to form a continuous distribution between 0 and 1. A uniform random variate is then chosen between 0 and 1 to determine which ship is struck for each hit during the operation.

Weapon Determination

The next step in the shipboard casualty simulation process is designation of the weapon type associated with each hit. Again using the empirical data, distributions of attacks by weapons, ships, and battle intensity levels were analyzed and percentage distributions were computed for 1) each weapon by ship combination, 2) weapons within each battle intensity level, and 3) overall

weapon distribution. These percentage distributions were determined from a matrix of weapon probabilities for each weapon hitting each ship type during each battle intensity. For cells where no events have occurred, a value for each weapon type was determined as follows:

$$W_{mjk} = O_m + (I_{mj} - O_m) + (T_{mk} - O_m)$$

where

m = weapon,
j = battle intensity,
k = ship type,
W_{mjk} = weapon m percent with battle intensity j and ship k,
O_m = overall proportion of weapon m striking any ship,
I_{mj} = proportion of weapon m striking during an operation of j battle intensity,
T_{mk} = proportion of weapon m striking ship type k.

Combining the probabilities of the different weapon and ship type combinations, as with ship type determination alone, yields a distribution between 0 and 1. A uniform random deviate is then chosen to determine the weapon that strikes the ship.

WIA and KIA

Empirical data[2] indicating the numbers of WIA and KIA sustained in various attacks were used to calculate the average number of casualties for different 'weapon by ship' combinations. Goodness of fit analysis indicated that shipboard WIA and KIA incidence are best represented by a Poisson process. SHIPCAS, therefore, yields its wounded and killed projections by drawing a random number from a Poisson process based on the mean frequency of casualties for each weapon by ship combination.

$$X \sim \text{Poisson}(\lambda)$$

where

x is the projected casualties (WIA or KIA) with estimated parameter λ.

In addition to these casualties, analysis of the historical data provided information on casualties that occur during operations that are not dependent upon a ship being hit. These 'background' casualties, which may result from events such as the firing of weapons, near misses, or defensive maneuvers, are derived by drawing a random deviate from a normal distribution surrounding the mean background casualties observed for that particular battle intensity. Once the total numbers of casualties is projected, the WIA and KIA rates per 1000 strength per day are computed based on the crew complements of each ship.

DISEASE AND NONBATTLE INJURIES (DNBI)

Studies have indicated that ship type is a significant factor in disease and non-battle injury incidence[3] while combat status had little practical effect on DNBI incidence[4,5]. Rates of DNBI, therefore, are averaged across the different ship types in the task force and provide and the basis for the simulation of disease and non-battle injury rates. Mean rates of DNBI incidence are

transformed into frequencies, based on the designated length of the operation and the crew complements, and DNBI projections are then generated by drawing a deviate from a normal random distribution. This quantity is then partitioned into a disease component and a non-battle injury component based on distributions observed in the empirical data[4].

CONCLUSIONS

The shipboard casualty projection system allows estimates to be made of the likely casualties to be sustained for various naval combat scenarios. These forecasts may, in turn, be used as input to the types of models which determine the specific bed, supply, and health care personnel requirements[7,8]. The large amount of empirical data provides the foundation for generating accurate projections from SHIPCAS. It is noted, however, that these projections are based on ship structures and weapon systems which have since underwent significant technological advances. Quantification of the impact of these developments is the next necessary step in accurate shipboard casualty forecasting.

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A shipboard casualty projection system (SHIPCAS) has been developed. This paper provides the statistical foundation of SHIPCAS and a guide to use of the projection system. Casualty data were extracted from eighty U.S. naval operations during World War II. The statistical distributions of hit rates, WIA, KIA, and DNBI incidence were analyzed by battle intensity, weapon system, and ship type; this data provides the basis for ship hit and casualty incidence projections. The SHIPCAS shipboard casualty projection system simulates casualty and illness rates under user defined naval scenarios. Output of the simulated data refects the salient characteristics of the empirical data.

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